

Using an InGrid Detector to Search for Solar Chameleons with CAST

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We report on the construction, operation experience, and preliminary background measurements of an InGrid detector, i.e. a MicroMegas detector with CMOS pixel readout. The detector was mounted in the focal plane of the Abrixas X-Ray telescope at the CAST experiment at CERN. The detector is sensitive to soft X-Rays in a broad energy range (0.3–10 keV) and thus enables the search for solar chameleons. Smooth detector operation during CAST data taking in autumn 2014 has been achieved. Preliminary analysis of background data indicates a background rate of $1 - 5 \times 10^{-5} \text{ keV}^{-1} \text{ cm}^{-2} \text{ s}^{-1}$ above 2 keV and $\sim 3 \times 10^{-4} \text{ keV}^{-1} \text{ cm}^{-2} \text{ s}^{-1}$ around 1 keV. An expected limit of $\beta_\gamma \lesssim 5 \times 10^{10}$ on the chameleon photon coupling is estimated in case of absence of an excess in solar tracking data. We also discuss the prospects for future operation of the detector.

1 The CAST experiment

The CERN Axion Solar Telescope (CAST) [1] is operating since 2003 in search for the emission of axions from the Sun through their conversion into soft X-Ray photons in the strong magnetic field of an LHC dipole prototype magnet. The experiment has been setting the strongest bounds on solar axion production to date [2]. More recently, CAST is extending its scope, making use of the versatility of the experimental setup. These extensions include the search for solar chameleons both through their coupling to photons [3] and through their coupling to matter [4] as well as the search for relic axions exploiting resonant microwave cavities immersed into the magnetic field [5]. In these proceedings we report about the progress in the search for solar chameleons using an InGrid detector, extending the preliminary results reported at the 2014 Axion-WIMP workshop [6].

2 Solar Chameleons

The observation of a non-vanishing cosmological constant, dubbed Dark Energy (DE), is arguably one of the greatest mysteries of modern physics. There exist only very few particle physics approaches to explain DE. The observed accelerated expansion of the universe may be explained by the existence of a scalar field. One such scenario is the so-called chameleon for which a low-energy effective theory has been formulated [7]. The chameleon field acquires an effective mass through a screening potential which establishes a non-zero vacuum expectation value depending on the surrounding matter density. The screening potential assures the

suppression of measurable fifth force effects and leads to a chameleon mass which depends on the ambient matter density. Chameleons, similar to axions, can be created via the Primakoff effect in strong electro-magnetic fields present in the Sun and observed on Earth through their back-conversion into detectable X-ray photons within a strong magnetic field via the inverse Primakoff effect. The energy of the photons is essentially equivalent to the chameleons' thermal energy during their production in the Sun. While axions may be created in the core of the Sun with a spectral maximum at approximately 3 keV, chameleons are predicted to be created in the solar tachocline [8] around $0.7 R_{\odot}$ where intense magnetic fields are present. Thus, they are produced at lower temperature corresponding to a spectral maximum of only 600 eV, requiring photon detectors with sub-keV sensitivity. An initial search for solar chameleons with CAST has been conducted using a Silicon Drift Detector [3].

3 InGrid Detector

An InGrid (“Integrated Grid”) is a gas-amplification device based on the MicroMegas principle. A thin aluminum mesh is mounted approximately $50 \mu\text{m}$ above a CMOS pixel chip, in our case the TimePix ASIC [9], via photolithographic wafer post-processing techniques [10]. The input pads of the pixels' charge-sensitive amplifiers serve as charge-collecting anodes and the collected charged is amplified and processed digitally in-situ. The pixel pitch is $55 \times 55 \mu\text{m}^2$. With this fine pitch, a typical gas amplification of ~ 3000 and a detection threshold of $\lesssim 1000$ electrons, a single electron efficiency of $>95\%$ is achieved. Given the diffusion of the ionization electrons from the photo electron, this allows for the counting of the total number of created electrons on the pixel chip and yields a direct measure of the energy, free of fluctuations in the amplification region. As the range of the photo electron in the detector gas (97.7% Argon, 2.3% Isobutane) is only few hundred microns, the image of an absorbed photon is an essentially circular cloud of hit pixels, where the cloud radius decreases with the absorption depth of the photon. This pattern provides an effective template which differs significantly from charged particle background (e.g. cosmic muons or electrons from β -decay) which produces typically a track-like pattern on the pixel chip. These differences are exploited to provide a powerful topological background suppression. The detector and its installation in CAST is explained in more detail in [6, 11] where also sensitivity of the detector down to below 300 eV has been demonstrated.

4 Results and Prospects

In autumn 2014, the detector has, for the first time, been taking data on 27 consecutive days including 1.5 h of daily solar tracking. While the solar tracking data are still blinded, the in-situ background data are being analysed using a simple three-variable likelihood for the photon hypothesis. In comparison to [6], the likelihood has been further tuned to reduce energy-dependent biases. A preliminary background spectrum is shown in Fig. 1. In the region above 2 keV two peaks around 3 keV and 8 keV are visible. The former corresponds to the known fluorescence line of Argon while the latter is likely a superposition of Copper fluorescence and cosmic tracks which traverse the detector parallel to the drift field. Such cosmics produce a m.i.p. signal which, due to the track's direction, is difficult to distinguish from a photon via topological suppression alone. Outside these peaks, the background level is around $1 - 2 \times 10^{-5} \text{ keV}^{-1} \text{ cm}^{-2} \text{ s}^{-1}$. There is a notable increase in background for energies below 2 keV,

reaching $\sim 3 \times 10^{-4} \text{ keV}^{-1} \text{ cm}^{-2} \text{ s}^{-1}$ around 1 keV. The origin of this background needs further study.

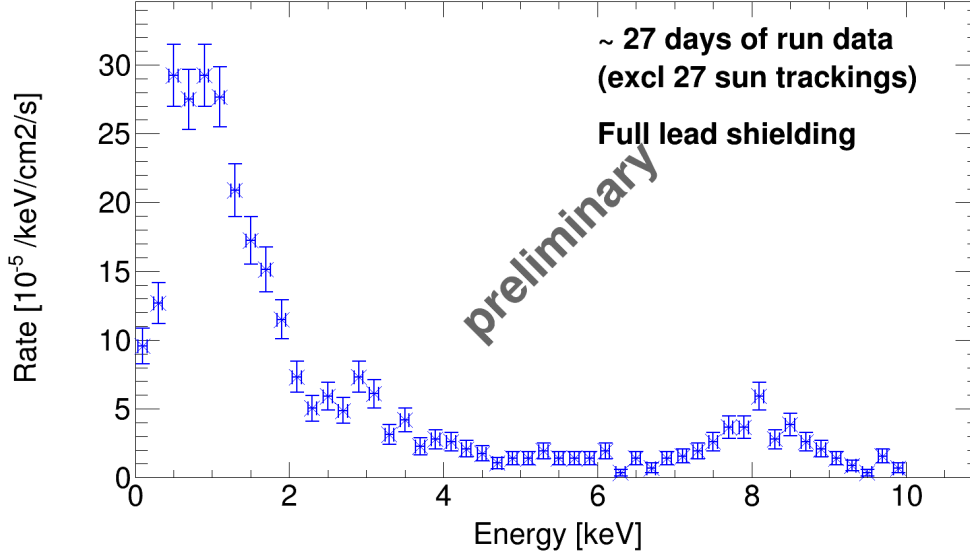


Figure 1: Preliminary background rate of InGrid Detector during operation in CAST in autumn 2014.

While the solar tracking data of the 2014 run have not yet been analyzed, one can already estimate an expected limit in case of non-observation of an excess. Our estimates are based on scaling the limit of the SDD detector [3] and accounting for scaling factors in exposure time, effective sensitive area, background, and efficiency. In Fig. 2 the estimated expected limit of the chameleon-photon coupling β_γ from the InGrid detector is shown together with the observed SDD limit and other experimental and astrophysical constraints. It can be seen that the 2014 InGrid data have the potential to set a limit $\beta_\gamma \lesssim 5 \times 10^{10}$, improving the SDD limit by almost a factor two under the same model assumptions as given in [3]. Also shown are prospects for data taking in 2015 and 2016. At the time of writing, the detector has been continuously taking data in the 2015 CAST run using the same setup as in 2014. Further improvements in background suppression (external cosmic veto, additional readout of the grid signal) and photon detector efficiency (through thinner X ray windows) as well as improvements in the software rejection of background are currently being developed and will be implemented step-wise. Rough estimates for the potential of these improvements yield expected exclusions are also shown in Fig. 2.

5 Acknowledgments

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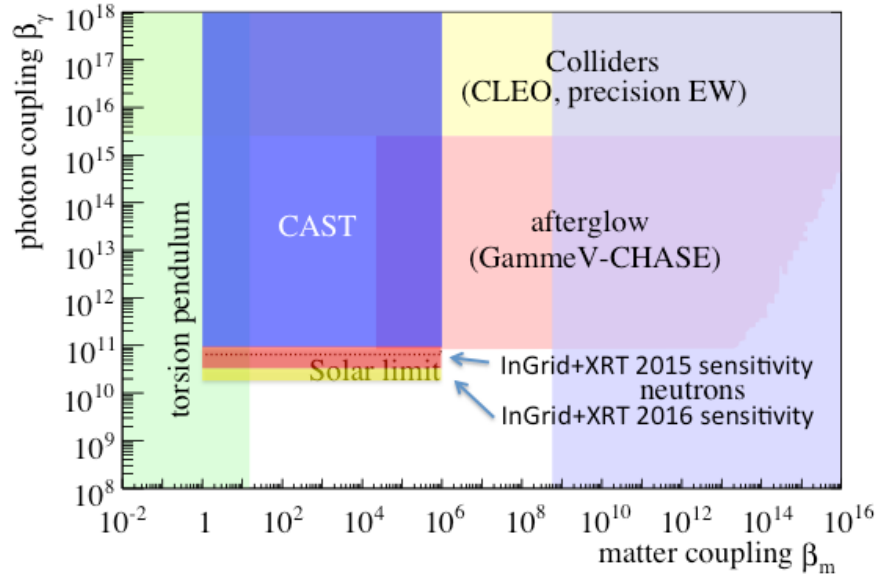


Figure 2: Exclusions in the plane of chameleon-matter coupling β_m vs. chameleon-photon coupling β_γ . Figure from [3] and modified to include InGrid detector prospects.

6 Bibliography

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